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VERTICAL IMPACT TESTING OF TWO HELMET-MOUNTED NIGHT VISION SYSTEMS

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FOR THE COMMANDER

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The Air Force is investigating the use of helmet-mounted technology to improve pilot performance. One potential draw-back to the new helmet systems is the potential for increased neck injuries during emergency ejection due to the helmet's weight and center-of-gravity. A recent test program evaluated the risk of neck injury of two helmet-mounted night vision systems by subjecting an instrumented manikin (ADAM) to +Gz impacts using a vertical deceleration tower. The helmets were the Concept VI from Night Vision Corporation, and the ANVIS 49/49 from ITT. Results indicate that both helmets were lighter than previous helmets, and met the Interim Head and Neck Criteria. They also produced neck loads in an ACES II seat that are less than what a standard helmet produces in a B-52 seat, and produced neck loads in a B-52 seat that are less than the maximum (400 lbs) required for major neck injury (fracture, etc.).

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PREFACE

An experimental effort was conducted to measure the biodynamic response of an Advanced Dynamic Anthropomorphic Manikin (ADAM) subjected to simulated ejection seat catapult dynamics while wearing either the ANVIS 49/49 helmet-mounted night vision system, or Night Vision Corporation's Concept VI helmet-mounted night vision system. The test results were used to determine the ejection safety (catapult phase only) of the helmet systems relative to a worse case USAF ejection seat environment, and relative to the USAF Interim Head/Neck Criteria for helmet-mounted systems. The tests were conducted for the AL/CFA Helmet Mounted System Technology System Program Office (HMST SPO), and the USAF 158th Fighter Group, by the Escape and Impact Protection Branch of the Armstrong Laboratory.

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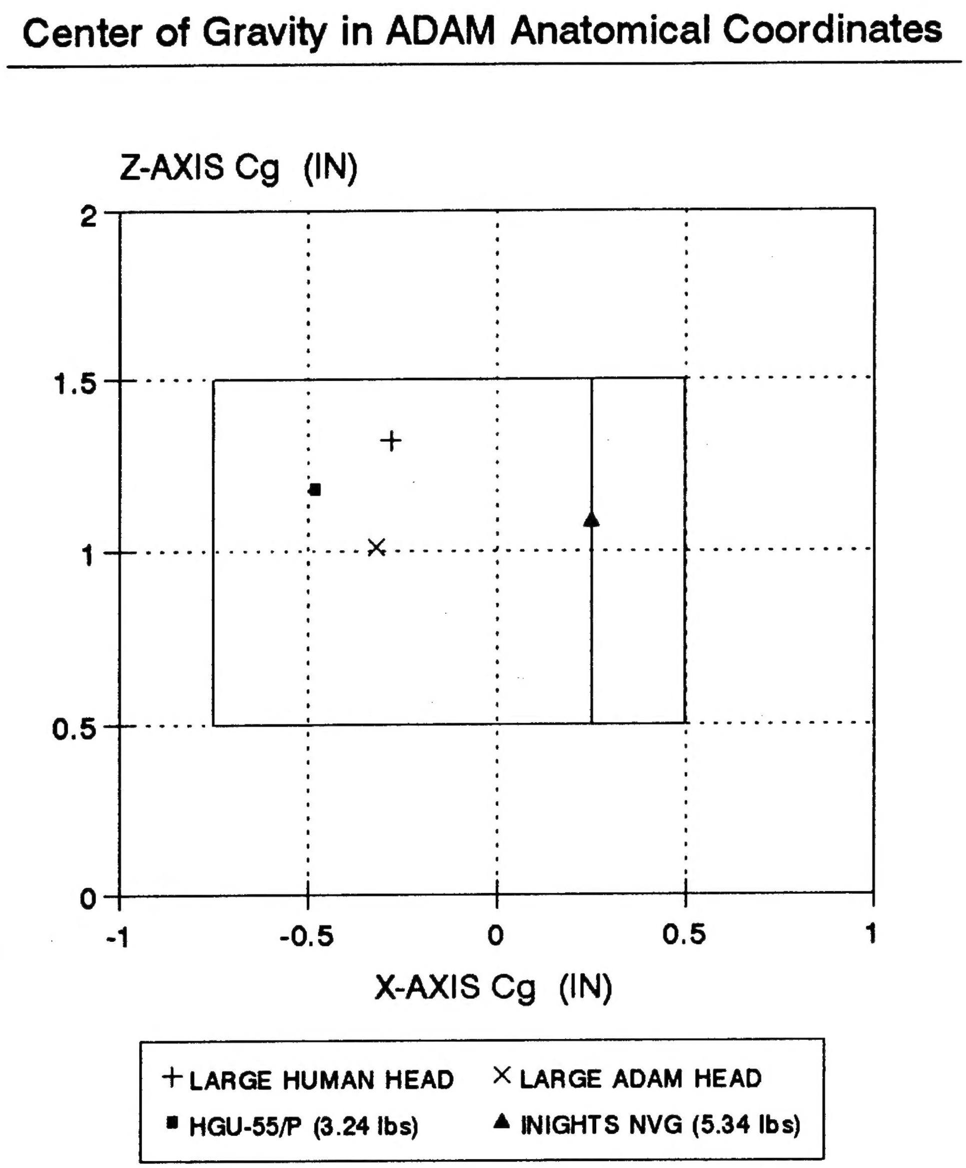
INTRODUCTION AND BACKGROUND

New and improved flight control systems are allowing pilots to fly mission profiles that are higher, farther, and faster. To improve pilot performance during a mission, the Air Force has been investigating the use of helmet-mounted visually coupled systems such as night vision devices or goggles, and helmet-mounted display systems. However, these systems which are designed to improve performance, may only increase the potential for neck injury during emergency escape from the aircraft using a ballistic ejection seat. The increase in the potential for neck injury is due to the use of the helmet as a platform which can alter the total head supported weight and the combined head and helmet system center-of-gravity (Cg).

Literature reviews have shown past research efforts concentrating on helmet weight relative to muscle fatigue in both normal- and sustained-G flight environments. Helmet weights in the range of 4 to 5 lbs maximum have been recommended. Only recently (last 5 years) has sustained research been initiated to examine the relationship between helmet inertial properties (weight and Cg) and the biomechanics of the neck during the impact acceleration experienced during emergency ejection. An ad-hoc working group based at the Escape and Impact Protection Branch (AL/CFBE), Wright Patterson AFB, and chaired by Dr. Francis S. Knox, was established to review past and current research efforts, accident statistics, and published literature. The reviews were conducted in order to develop interim head criteria on maximum head supported weight and altered Cg in order to minimize neck injury during ejection. In December 1991, a report entitled *Interim Head and Neck Criteria* was completed and sent to HSD/YA at Brooks AFB. Figure 1 summarizes the results of the report and shows that for helmet weights less than 5.0 lbs for the ACES II seat and for helmet weights less than 4.0 lbs for the B-52 seat, the Cg of the helmet system must lie inside the outer box. A helmet system used with a B-52 seat can also weigh up to 4.5 lbs, but must lie inside the second inner box. Currently, a research effort is under way at AL/CFBE to investigate parametric shifts in weight and Cg at various acceleration levels. It is anticipated the results of this study will be used to update the current Interim Head and Neck Criteria.

Recently, a test program at AL/CFBE was conducted to evaluate the risk of neck injury of two helmet-mounted night vision systems. This special report will document the research conducted to evaluate the biodynamic response of a manikin wearing the ANVIS 49/49 or the Night Vision Corporation Concept VI night vision goggle systems in a simulated ejection environment.



Outer Box Cg Limits: Weight Criteria... 4.0 lb for B-52 seat, 5.0 lb for ACES II
Inner Box Cg Limits: Weight Criteria... 4.5 lb for B-52 seat

FIGURE 1. INTERIM HEAD AND NECK CRITERIA

METHODS

To evaluate the potential for an increase in the risk of neck injury during ejection while wearing a helmet-mounted night vision device or goggle, a series of impact tests were conducted to simulate both an ACES II and a B-52 ejection seat pulse. The series of short duration, +Gz impact acceleration tests were conducted using the AL/CFBE Vertical Deceleration Tower (VDT) and a large, instrumented Advanced Dynamic Anthropomorphic Manikin (ADAM) as shown in Figure 2. The VDT simulates the ACES II seat with the 10 G impact pulse, and simulates the B-52 seat with the 15 G impact pulse. These pulse shapes are shown in Figure 3. The simulation of the ejection seats is based on matching DRI values (spinal injury predictions) of the seat acceleration and the VDT acceleration, and not on matching identical pulse shapes. The VDT functions to generate an acceleration pulse by producing a +z-axis (inferior to superior along spine) impact acceleration, which approximates the catapult acceleration, using a hydraulic decelerator. A seat pan and seat back configuration and a restraint system are mounted to a carriage which can move vertically on guide rails. The carriage and a test subject are hoisted to a pre-determined height and then allowed to free-fall. A contoured plunger mounted on the bottom of the carriage is then guided into a water-filled cylindrical reservoir. The force generated by the plunger displacing the water as it enters the cylinder is what produces the deceleration or impact profile. The VDT acceleration profile is determined by the height of the carriage at free-fall (controls acceleration magnitude), and the shape of the plunger (controls acceleration "rise-time" or "time to peak").

The test facility was instrumented to collect seat pan loads and seat accelerations, and the z-axis acceleration of the VDT carriage. The ADAM was instrumented to collect linear head and chest accelerations, and angular head and chest velocities. The ADAM also allows the instrumentation of the cervical neck with a Denton six-axis load cell to collect forces and torques at the occipital condyle (point where the skull joins the neck at C1 or the Atlas). The USAF standard lap belt and shoulder harness, used to restrain ADAM in the test seat on the VDT, was also instrumented to measure the forces generated in the restraint system. All accelerations, velocities, and forces were collected with an on-board automatic data acquisition system (ADACS) mounted on the VDT (The ADACS is mounted above the seat under the tarp as shown in Figure 2). Each test was documented with an on-board KODAK High-Speed Video System which captured the detailed movements of ADAM and the helmet system during the impact acceleration.

For this test program, the two NVG helmet systems were tested three times at both 10 and 15 G. A simple HGU-55/P helmet was also tested at 10 G for baseline data and for comparison to

the other systems. An MBU-12/P oxygen mask was used with each helmet for all tests. Figures 4 and 5 show the NVG systems that were tested.

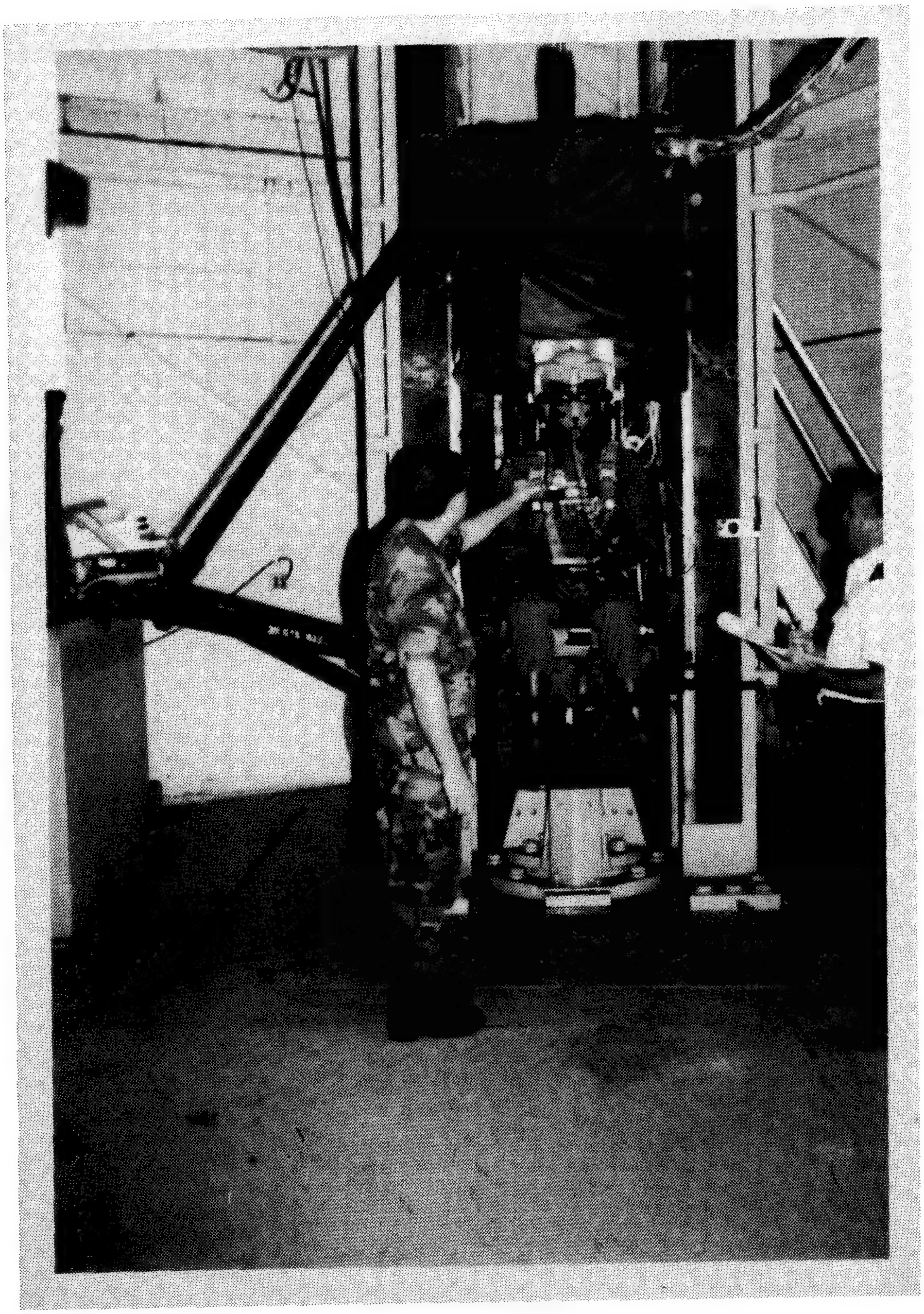


FIGURE 2. VERTICAL DECELERATION TOWER (VDT) USED FOR NVG TESTS

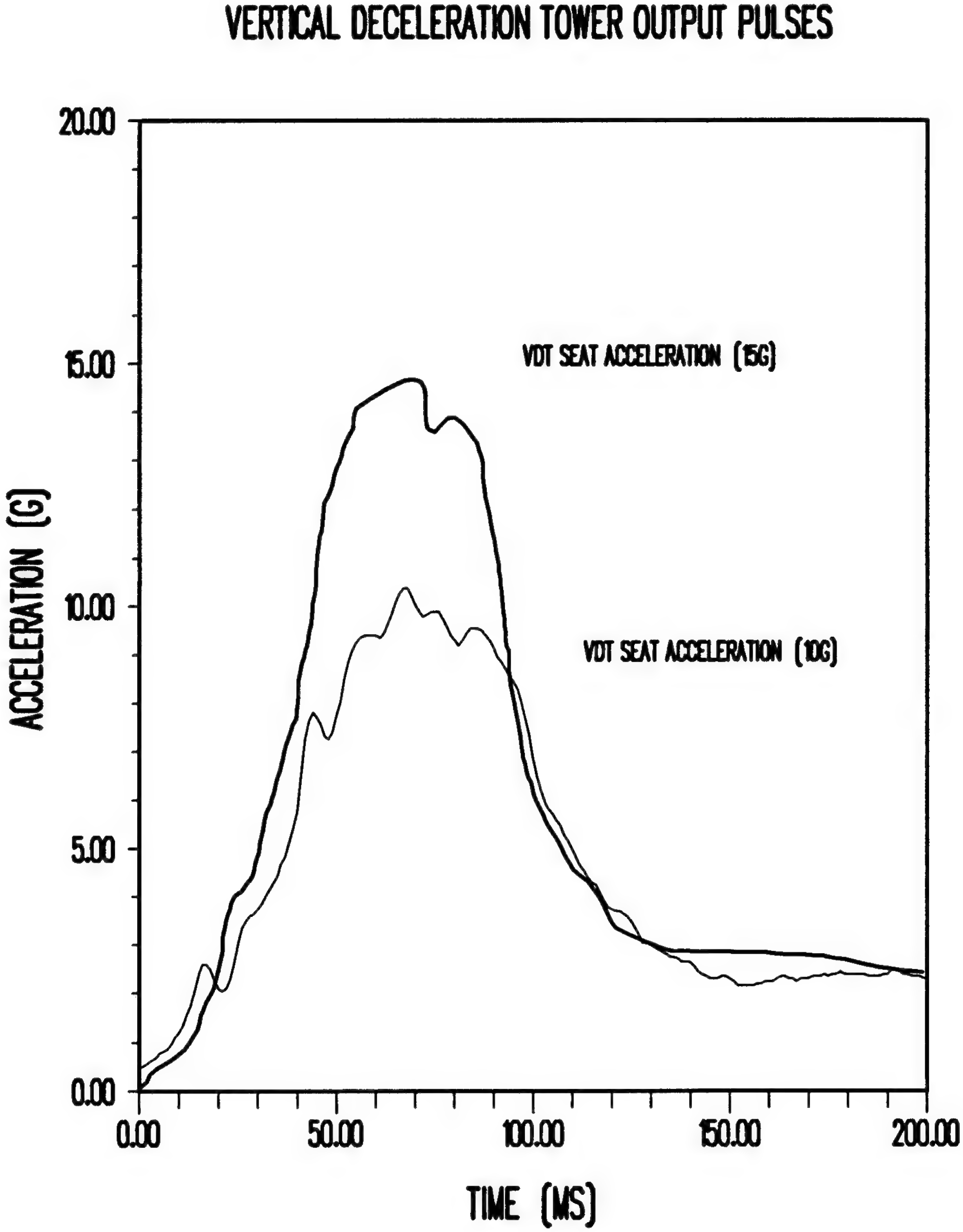


FIGURE 3. VDT 10 AND 15 G PULSE SHAPES

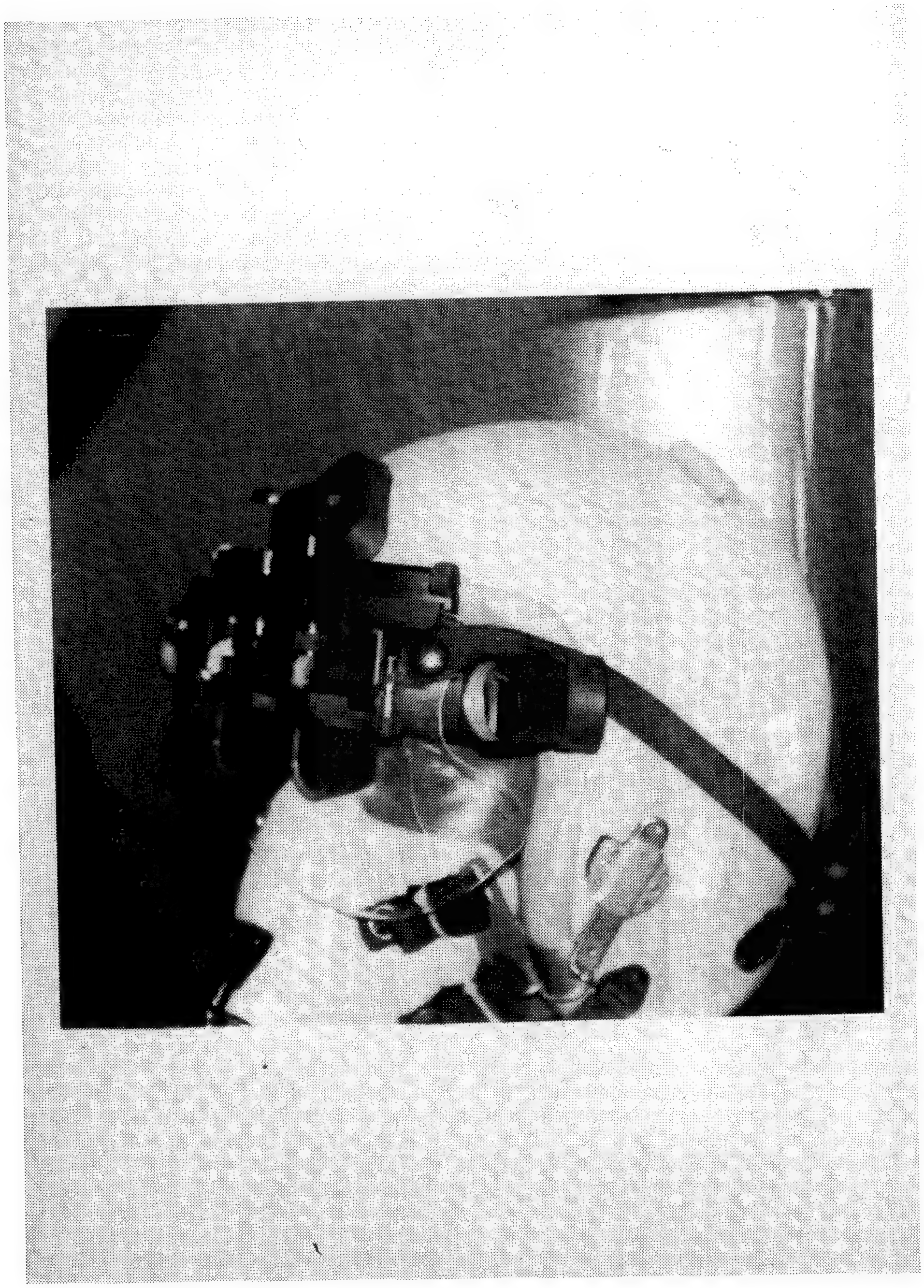


FIGURE 4. CONCEPT VI HELMET-MOUNTED NVG SYSTEM

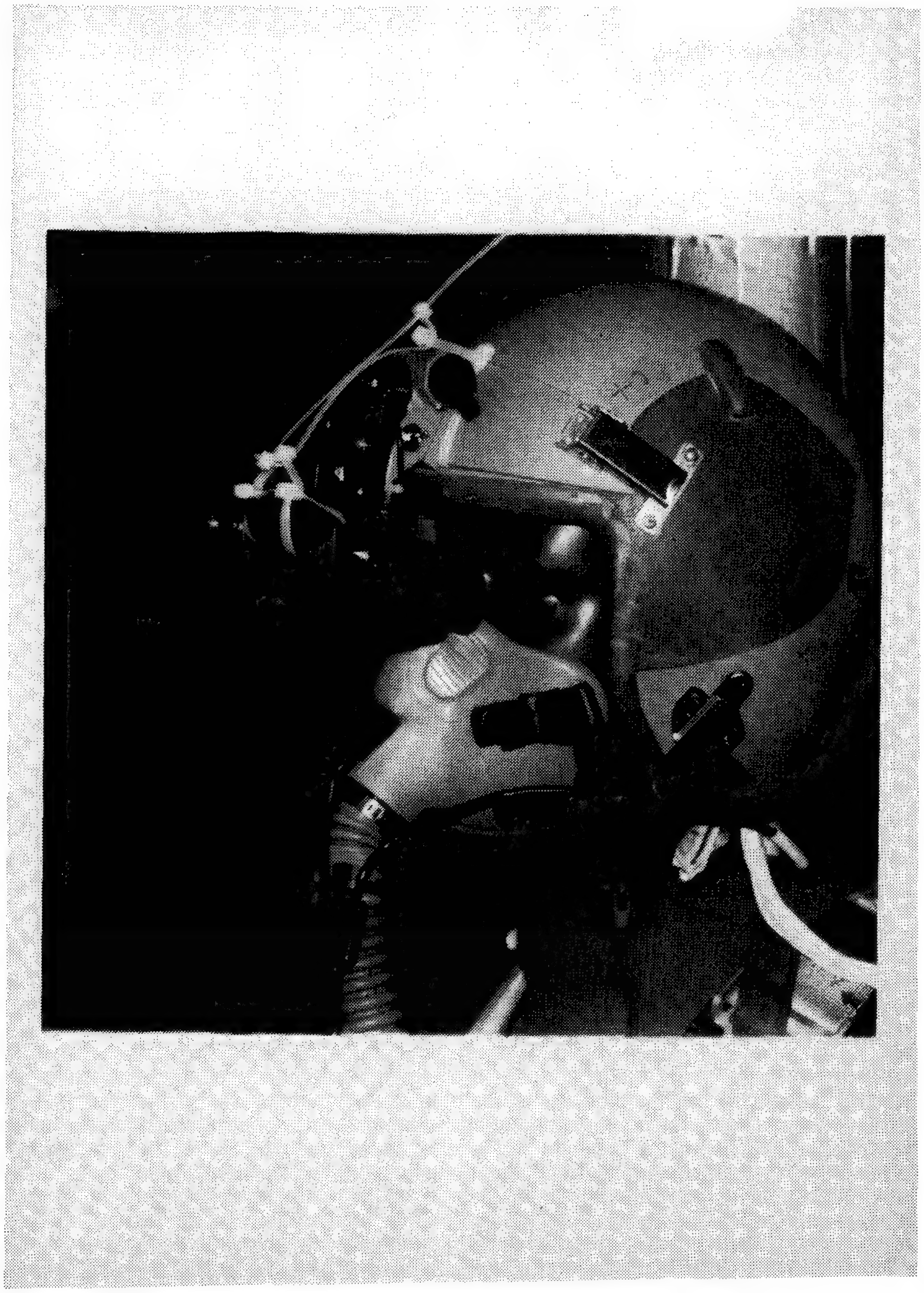


FIGURE 5. ANVIS 49/49 HELMET-MOUNTED NVG SYSTEM

Table 1 details the VDT test matrix used for this program.

Table 1. NVG Impact Test Matrix

Test Cell	No. of Tests	Accel Level	Helmet System	NVG System
A	3	10 G	HGU-55/P	None
B	3	10 G	HGU-55/P	Concept VI
C	3	10 G	HGU-55/P	ANVIS 49/49
D	3	15 G	HGU-55/P	Concept VI
E	3	15 G	HGU-55/P	ANVIS 49/49

In addition to the impact testing conducted on the VDT, the inertial properties of the helmet systems were also measured to determine system weight (with and without the helmet and mask), center-of-gravity relative to the ADAM anatomical axis system, and the moment of inertia. This was accomplished in order to combine the helmet systems with the inertial properties of the ADAM headform, and to allow the development of relationships between helmet system inertial properties and the biodynamic response of humans or manikins wearing the helmet system. This procedure was completed prior to testing on the VDT, by the Vulnerability Assessment Branch of the Armstrong Laboratory (AL/CFBV).

Analysis of the ADAM data included review of all neck loads, and then comparisons to the Interim Head/Neck Criteria and to data from the baseline configuration. The compression loads (z-axis) and the shear loads (x-axis) measured by the ADAM's neck load cell, are good estimates of the loads that may be experienced by human subjects; however, the human My neck torque (rotation of the head around the y-axis) had to be estimated by the following regression equation:

$$T_H = 699.2 + [(-355.5 * Hwt) + (44.3 * Hwt^2)] + (1.796 * T_M)$$

where T_H is the estimated human My Torque, Hwt is the helmet weight, and T_M is the torque measured by the ADAM manikin neck load cell.

RESULTS

The specific objective of the impact tests was to evaluate the biodynamic response of the ADAM neck to +Gz impacts when the ADAM headform was encumbered by either of two helmet-mounted visually coupled NVG systems. Part of the biodynamic evaluation of the helmet systems was the collection and analysis of inertial property data. All the data is relative to the ADAM anatomical axis system defined by the line (y-axis) connecting the right and left tragion (notch above ear canal), a line (x-axis) connecting the infra-orbital notch and the y-axis and shifted equidistantly between the tragion, and a line (z-axis) perpendicular to the intersection of the x and y-axis. The intersection of all three axis forms the origin of the anatomical axis system. The Cg's of the helmets are referenced to this point. The axis system is shown in Figure 6.

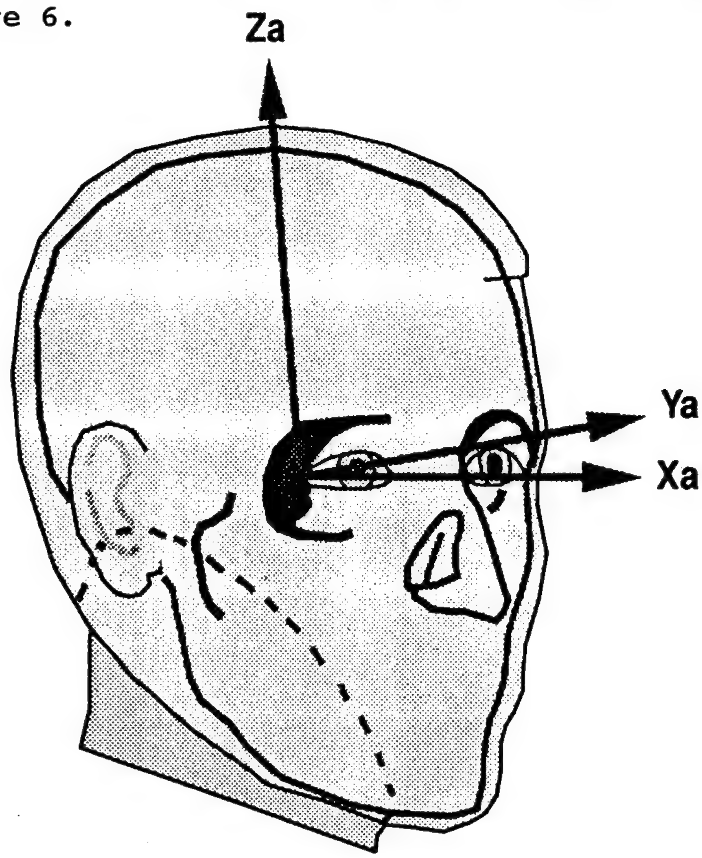


FIGURE 6. HEADFORM ANATOMICAL AXIS SYSTEM

A summary of the inertial properties of the baseline system and the ADAM headform is shown in Table 2. The data for the helmet, mask, and helmet/mask combination is relative to the ADAM anatomical coordinate system, but does not include the properties of the headform. The next to last entry in the table shows the properties of the ADAM headform plus the standard helmet and mask. Notice that the combined headform and helmet system Cg is close to the Cg of the bare ADAM head. Table 2 also contains data on a prototype helmet system previously analyzed for weight and Cg, and tested for impact response. The helmet was from the Interim-Night Integrated Goggle and Head Tracking Systems (INIGHTS) test program, and was also compared against the Concept VI and the 49/49. Table 3 contains inertial property data for the two NVG systems, one mounted on an HGU-55/P and the other on an HGU-53/P helmet with the MBU-12/P mask. The helmet data is shown including and not including the ADAM headform. The 49/49 system (4.63 lbs) is lighter than the Concept VI system, but has a greater Cg shift in the x-axis and the z-axis compared to the Concept VI. The 49/49 also displays a larger z-axis moment which would indicate rotating the head in yaw could be more difficult than with either a standard helmet or the Concept VI helmet system. Compared to the INIGHTS prototype, the 49/49 is lighter (0.71 lbs), has approximately the same Cg specifications, and has a better moment of inertia for the x-axis. In converse, the Concept VI helmet (4.87 lbs) is heavier than the 49/49 by approximately 0.25 lbs, and has a larger x-axis moment. This larger moment indicates that rotating the head in roll or a combination of roll and pitch will be more difficult than with the baseline helmet or the 49/49 helmet. The Concept VI is also lighter than the INIGHTS prototype, has a little better z-axis Cg, and has approximately the same moments of inertia.

A structural evaluation was also completed on each system to determine whether the NVG mounting techniques could withstand the forces generated during an ejection seat impact. The first mount sent with the ANVIS 49/49 system, cracked on the right side where it attached to the HGU-55/P helmet, after the second impact test at 10 G. It was replaced with a new mount that was sent by 158th Fighter Group (158FG/OLS), because it was known that the original mount was weak. The new mount successfully completed all remaining 10 g and 15 G tests with no problems. The Concept VI NVG mount had no structural failures during the course of the VDT testing, it was noted, however, that the mount did not rigidly attach to the helmet. This allowed the NVG's to move relative to the helmet during the test, but as stated before, there was no structural failure.

As shown in Figure 7, the helmet systems lie between the outer and the inner box indicating that because of their weight, they could successfully be worn with an ACES II ejection seat, but will probably cause some problems if worn with the B-52 ejection seat. These problems would include a definite increase

Table 2. Inertial Properties of Standard ADAM Headform and Standard Helmet System.

ITEM	WEIGHT (LBS)	CENTER OF GRAVITY (IN)	PRINCIPLE MOMENT OF INERTIA (LBS-IN ^ 2)
ADAM HEADFORM	8.93	-0.32 , -0.03 , 1.01	76.43 , 82.20 , 51.16
MBU-12/P MASK	0.75	3.88 , -0.01 , -2.99	5.84 , 5.61 , 2.56
HGU-55/P HELMET	2.49	-0.77 , 0.04 , 2.11	39.97 , 33.10 , 42.99
HGU-55/P + MBU-12/P	3.24	0.31 , 0.03 , 0.93	72.73 , 66.20 , 46.05
GEC INIGHTS NVG + 12/P	5.34	1.22 , -0.03 , 1.23	129.72 , 86.14 , 75.63
ADAM + 55/P + 12/P	12.17	-0.15 , -0.01 , 0.99	129.52 , 149.31 , 118.24
ADAM + GEC + 12/P	14.27	0.25 , -0.03 , 1.09	185.33 , 176.1 , 155.81

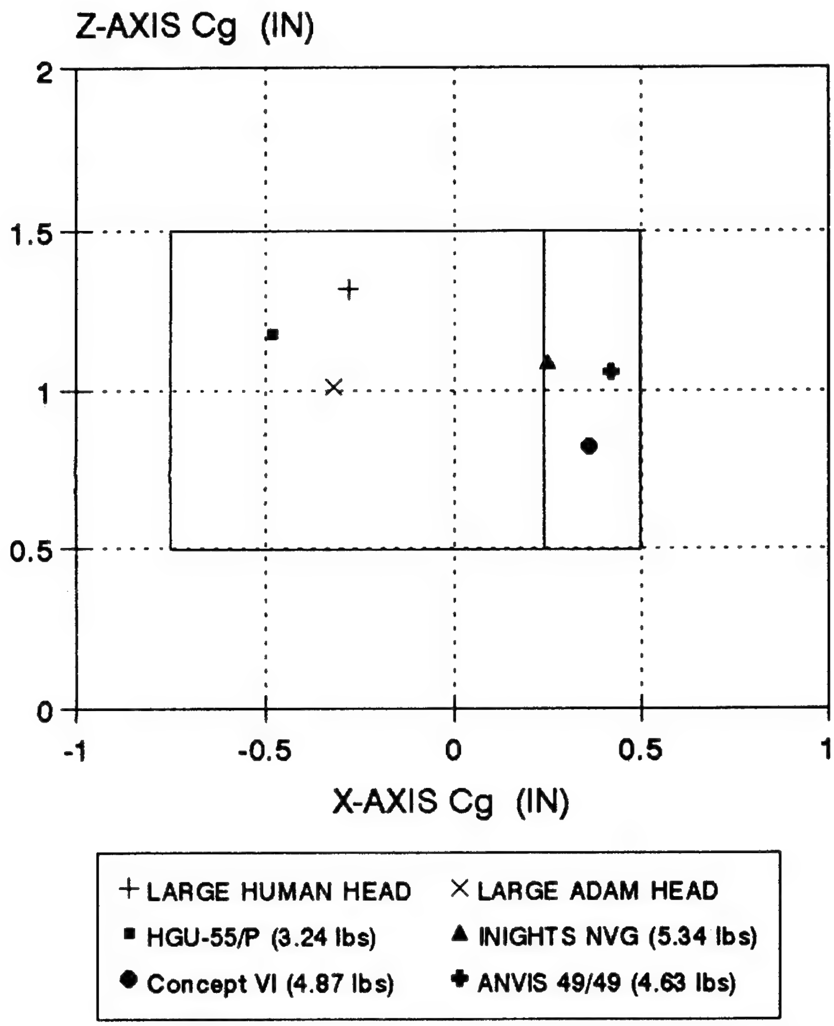
Note: Inertial data relative to ADAM head anatomical axis system.

Table 3. Inertial Properties of ADAM Headform and Various Helmet-Mounted Systems.

ITEM	WEIGHT (LBS)	CENTER OF GRAVITY (IN)	PRINCIPLE MOMENT OF INERTIA (LBS-IN ^ 2)
(1) ADAM HEADFORM	8.93	-0.32 , -0.03 , 1.01	76.43 , 82.20 , 51.16
(2) HGU-55/P, MBU-12/P	3.24	0.31 , 0.03 , 0.93	72.73 , 66.20 , 46.06
(3) 55/P, 12/P, 49/49	4.63	1.83 , 0.35 , 1.14	75.43 , 99.74 , 91.61
(4) 53/P, 12/P, CONCEPT VI	4.87	1.60 , -0.01 , 0.45	136.28 , 85.11 , 42.58
(5) ADAM HEADFORM + (2)	12.17	-0.15 , -0.01 , 0.99	129.52 , 149.31 , 118.25
(6) ADAM HEADFORM + (3)	13.56	0.42 , 0.11 , 1.06	121.14 , 198.23 , 178.35
(7) ADAM HEADFORM + (4)	13.80	0.36 , 0.21 , 0.82	172.95 , 183.66 , 134.44

Note: Inertial Data relative to ADAM head anatomical axis system.

Center of Gravity in ADAM Anatomical Coordinates



Outer Box Cg Limits: Weight Criteria... 4.0 lb for B-52 seat, 5.0 lb for ACES II
Inner Box Cg Limits: Weight Criteria... 4.5 lb for B-52 seat

FIGURE 7. INTERIM HEAD AND NECK CRITERIA RELATIVE TO TWO NVG SYSTEMS

in the percentage of minor neck injuries (strains and sprains), and a strong potential for an increase in the percentage of major neck injuries (tears and fractures).

Table 4 is a brief summary of some of the primary electronic data channels collected during each VDT test. These values can be related to maximum load values established by Mertz and Patrick using cadavers, and to values obtained from a simulation of a worse case USAF ejection pulse (B-52 seat) with a standard flight helmet (HGU-55/P). It must be mentioned that, after some analysis, all the recorded neck loads may be approximately 15% (corrected values will be shown in parenthesis in the text) less than what they should be based on a review of previous tests on the VDT with similar helmets. This may be due to the neck calibration, an instrumentation procedure, or normal variation in the impact acceleration input, all of which are being researched. As shown by the table, all the compressive neck loads in the z-axis are less than the 400 lb maximum load value as referenced from Mertz and Patrick. They determined that this load value may be the transition point from lower forces that cause no injury and/or minor sprains and strains, to higher forces that will cause major injuries such as ligamentous tears and compression fractures of the cervical vertebrae. Even with a 15% correction to the loads, they are close to the 400 lb limit but do not exceed it. This indicates that the NVG helmet systems are at a maximum in terms of weight and Cg parameters, and this is verified in Figure 7. Based on a 360 lb reference point obtained from the worse case ejection pulse, the two NVG systems have loads that are less than this value at 10 G's, and have loads that are approximately equal to it at 15 G's. Relative to the neck torque, all the helmets generated neck torques at both 10 and 15 G's, that were below the approximate maximum ADAM torque value as modified from a value determined by Mertz and Patrick. This occurred due to the fact that the helmet system inertial properties met the criteria as stated by the Interim Head and Neck Criteria.

Table 4. Helmet Mounted NVG Program: VDT Impact Data Summary.

Impact Acceleration (G)	Helmet System	ADAM Z-Axis Neck Load (LBS)	ADAM My Neck Torque (IN-LBS)	Human My Neck Torque (IN-LBS)
10	HGU-55/P	162.3	116.3	221.3
10	HGU-53/P + CONCEPT VI	193.1	157.3	301.1
10	HGU-55/P + ANVIS 49/49	191.2	149.6	276.6
15	HGU-53/P + CONCEPT VI	342.0	188.6	357.3
15	HGU-55/P + ANVIS 49/49	332.0	238.7	431.6

Notes:

(1) Load and torque data from ADAM Denton load cell.

(2) Maximum load criteria: Neck z = 400 lbs, Neck Torque (relative to ADAM) = 850 in-lbs.

CONCLUSIONS

In conclusion, the Concept VI helmet-mounted NVG system, and the 49/49 helmet-mounted NVG system are both lighter than previous prototype helmets as investigated during the INIGHTS test program. They both met the Interim Head and Neck Criteria in terms of weight and Cg. In terms of biodynamics, both helmet systems will generate neck loads, in an ACES II ejection seat environment, that are much less than the load generated by a standard helmet in the USAF worse case ejection seat. In a B-52 ejection seat, both helmet systems will generate neck loads that are approximately equivalent or a little greater than a standard helmet in the same environment, but less than the 400 lb maximum neck load value (minor/major injury transition point).

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